NODE PLACEMENT GUIDELINES FOR DISTRIBUTED
GROUND SENSOR SYSTEMS

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ABSTRACT[*]

Distributed sensor systems are currently being developed to meet a wide variety of program requirements related to the successful classification and tracking of ground vehicles and personnel. However, as the number of sensors detecting targets within a sensor field grows, accurate multi-sensor data fusion and tracking algorithms become increasingly critical in order to provide the war-fighter/end-user with a precise assessment of the activity within the sensor field. A simulation tool has been developed for the purpose of performing trade studies between data fusion/tracking algorithm performance and various nodal configurations within a given sensor field. Simulation results indicate that the proper placement of nodes within a sensor field is capable of providing significant improvements in system performance. It is anticipated that the simulation tool developed for this work will be used to assist in the sensor node placement for future field tests, exercises and operational scenarios.

INTRODUCTION

Distributed sensor systems are currently being developed to meet a wide variety of program requirements related to the successful classification and tracking of ground vehicles and personnel. However, as the number of sensors detecting targets within a sensor field grows, accurate multi-sensor data fusion and tracking algorithms become increasingly critical in order to provide the war-fighter/end-user with a precise assessment of the activity within the sensor field. In an earlier paper [1], significant differences in data fusion and tracking performance were observed for different nodal configurations within the same sensor field. Consequently, it is apparent that the system performance of distributed ground sensor systems is highly dependent upon the placement of the sensor nodes within a given sensor field.

This paper discusses the development of a simulation tool created for the purpose of performing trade studies between system performance (i.e., data fusion and tracking algorithm performance) and various nodal configurations for a given sensor field. The simulation tool allows the user to control the number and configuration of sensor nodes within a given sensor field in order to analyze system performance as a function of sensor node placement. Simulation results indicate that the proper placement of sensor nodes within a given sensor field is capable of providing significant improvements in system performance. It is

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Abstract

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anticipated that the simulation tool developed for this work will be used to assist in the sensor node placement for future field tests, exercises and operational scenarios.

"TRACK-TYPE" TRADE STUDIES

To begin, trade studies were performed for "track-types" expected to be observed in an actual sensor field. The "track-types" investigated for this work were as follows[1]:

1. Straight track
2. Curved track

For each "track-type" trade study, truth data was generated corresponding to the desired track-type, and bearing measurement data was created for each node based upon the truth data plus additive noise. The bearing measurement noise models were zero mean, normally distributed and scaled as a function of distance between the node location and the true target location. The distance scaling utilized for the bearing measurement noise models was based upon actual measurement data obtained from field tests conducted on the Aberdeen test-track located at Spesutie Island. Figure 1 illustrates the Aberdeen test-track and nodal configuration used to collect the measurement data for developing the simulation tool's noise models. Figure 2 illustrates the accuracy of the resulting synthesized bearing data using the developed noise models. From Figure 2 it can be seen that the synthesized bearing measurement data agrees quite well with the actual field test bearing measurement data. It should be noted that the "drop-outs" observed in Figure 2 corresponding to the actual bearing measurement data are not currently modeled in the synthesized bearing measurement data.
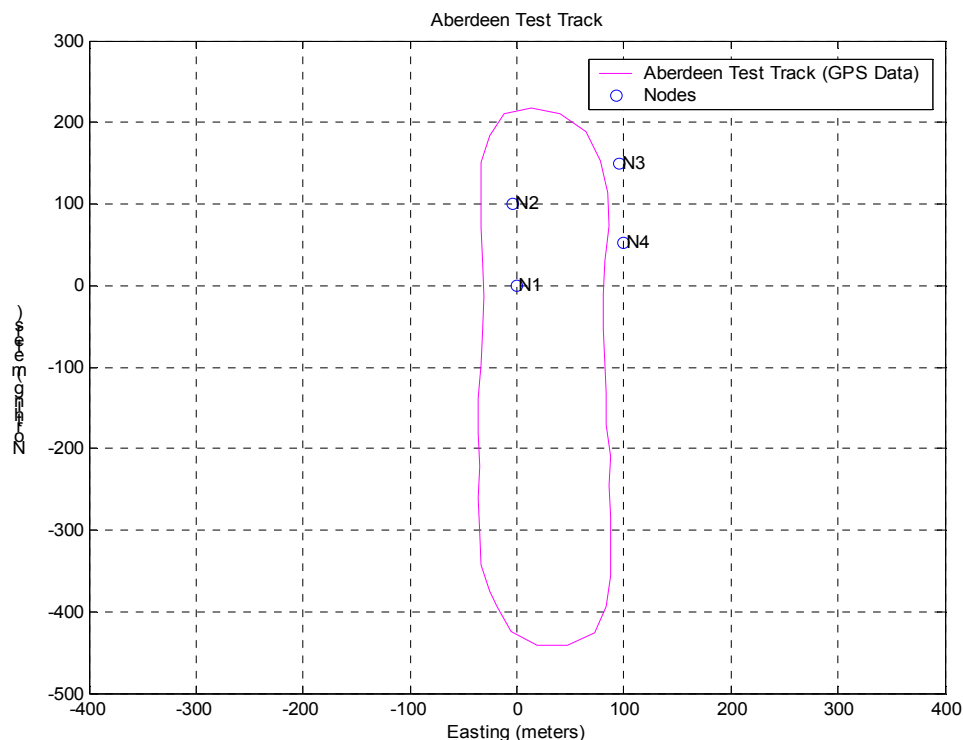

Figure 1 Node Configuration For Aberdeen Field Tests

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[1] It is believed that the two track-types mentioned above and their corresponding combinations cover the *majority* of expected track-types to be observed in any given sensor field.
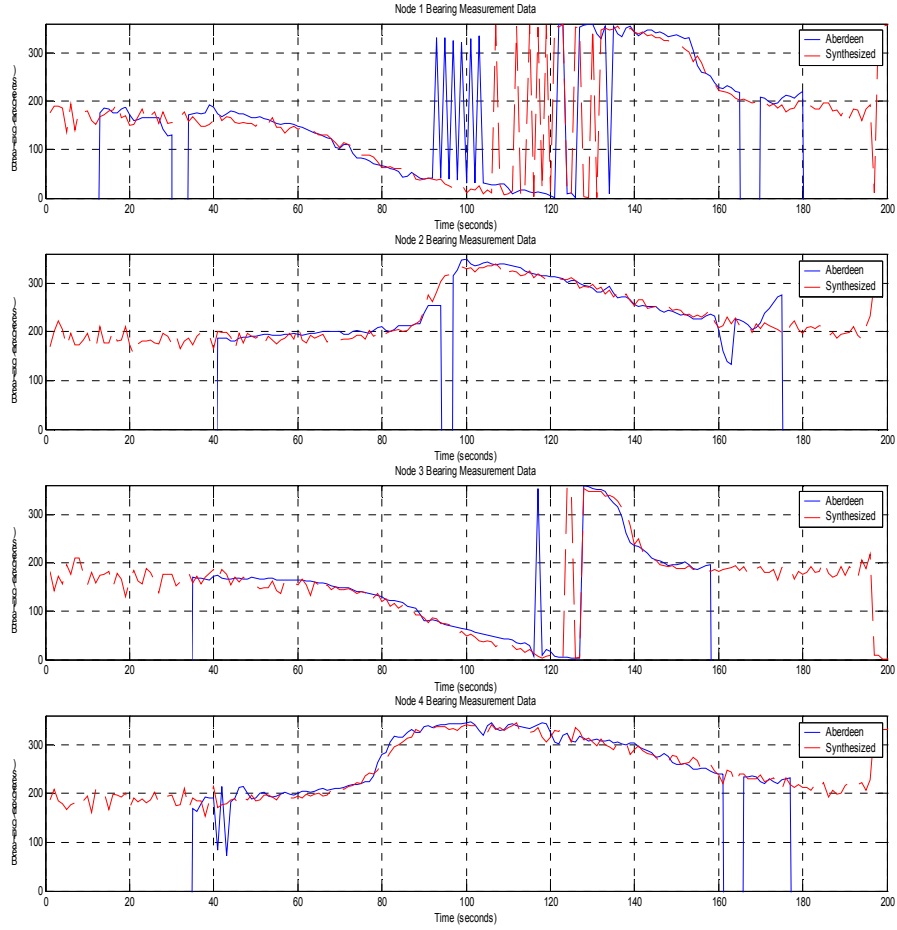
Figure 2 Comparison of Aberdeen Real & Synthesized Bearing
Measurement Data

The first "track-type" investigated was the straight track-type.   For this track-type, two nodal configurations were examined – a "box" configuration and a "diamond" configuration. Samples of system performance corresponding to the two nodal configurations for the straight track-type are illustrated in Figures 3 and 4. Monte-Carlo performance data is provided in Table 1[2].

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[2] All Monte Carlo performance data was based upon 50 runs with each run perturbing the individual nodal biases, scale factors and position uncertainties.
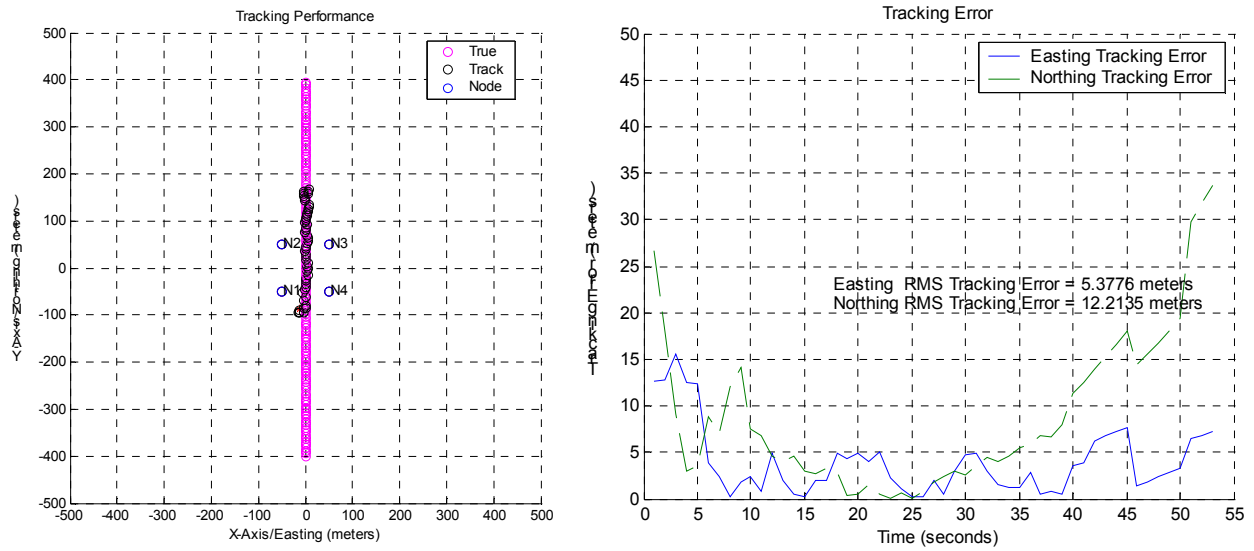
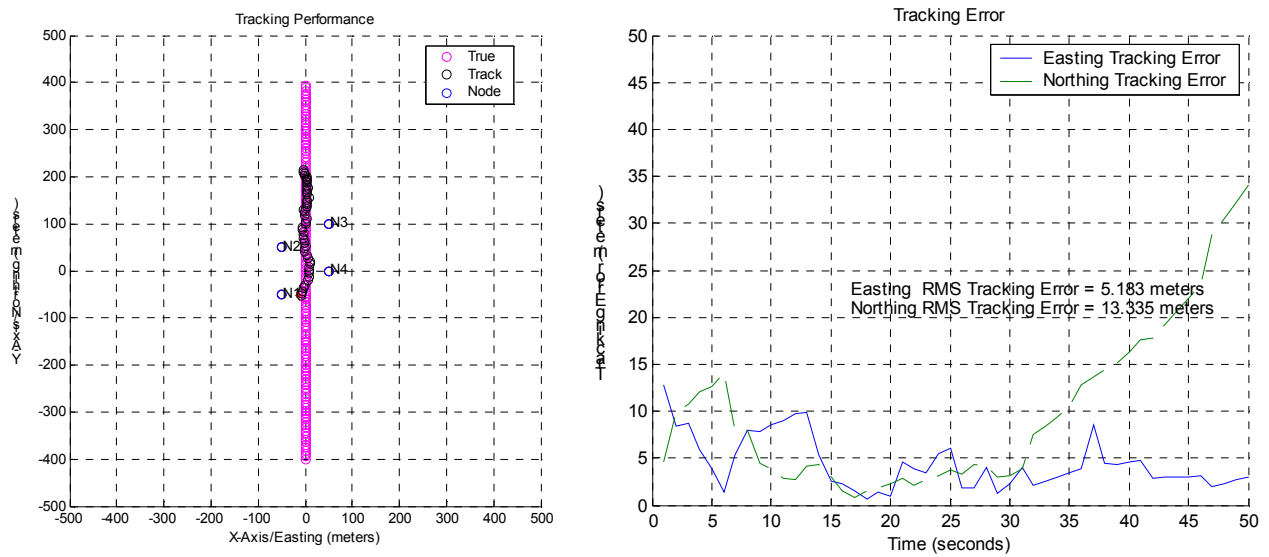Figure 3 Box Configuration Tracking Performance For Straight Track

Figure 4 Diamond Configuration Tracking Performance For Straight Track

Table 1 Straight Track Monte Carlo Results

Node Placement	X-Axis/Easting Error (m)			Y-Axis/Northing Error (m)			Spatial Coverage (m)		
	min	max	avg	min	max	avg	min	max	avg
Box	2.9	12.7	6.4	6.2	45.1	15.7	158	364	295
Diamond	2.5	15.9	6.7	5.8	55.1	18.7	139	376	288

From the Monte-Carlo results provided in Table 1, it was seen that the "box" nodal configuration and the "diamond" nodal configuration for the straight track-type were very comparable. However, the "box" nodal configuration appeared to provide the better combination of spatial coverage and rms tracking performance as compared to the "diamond" nodal configuration.

The second "track-type" investigated was the curved track-type. For this track-type, three nodal configurations were examined - a "box" configuration, a "diamond" configuration and a "skewed-diamond" configuration. Samples of system performance corresponding to the three nodal configurations for the curved track-type are illustrated in Figures 5-7. Monte Carlo performance data is proved in Table 2.
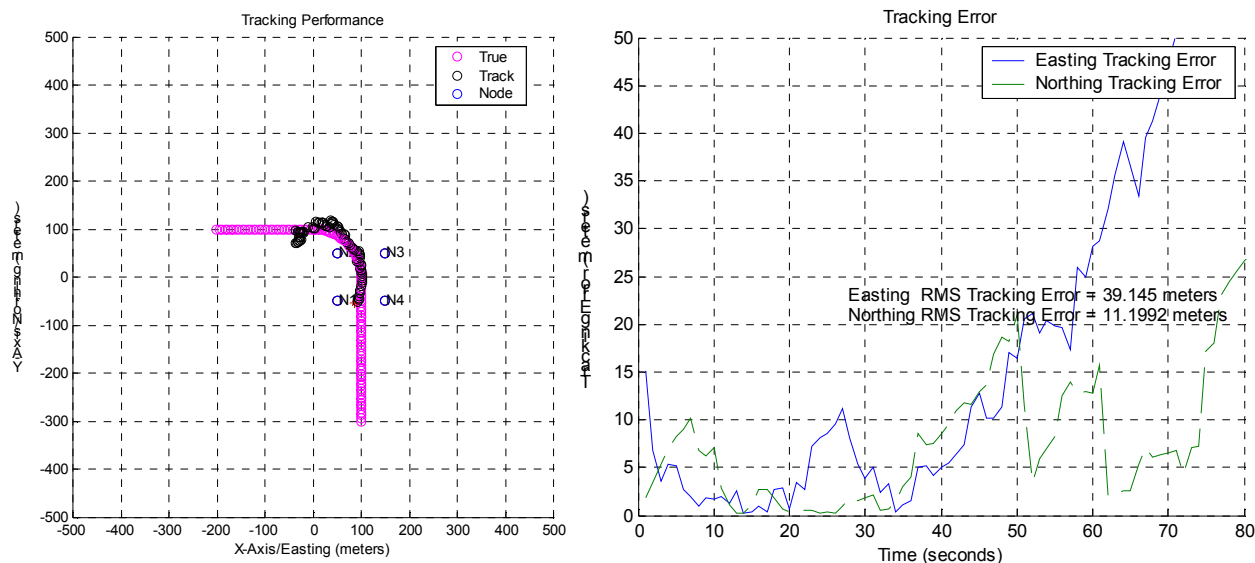

Figure 5 Box Configuration Tracking Performance For Curved Track
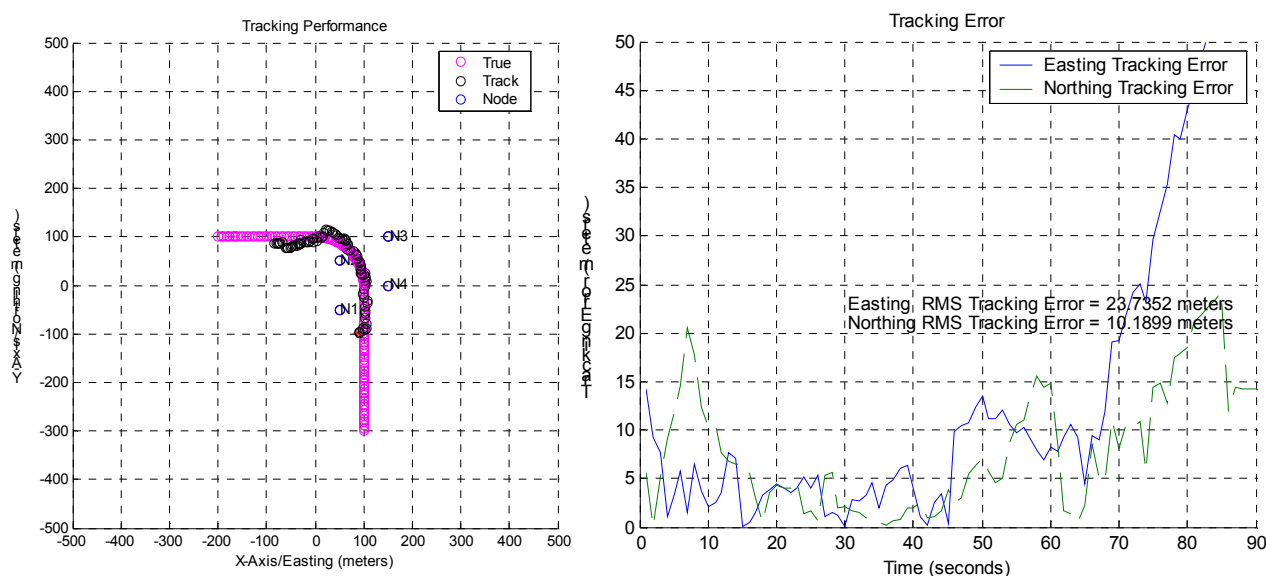

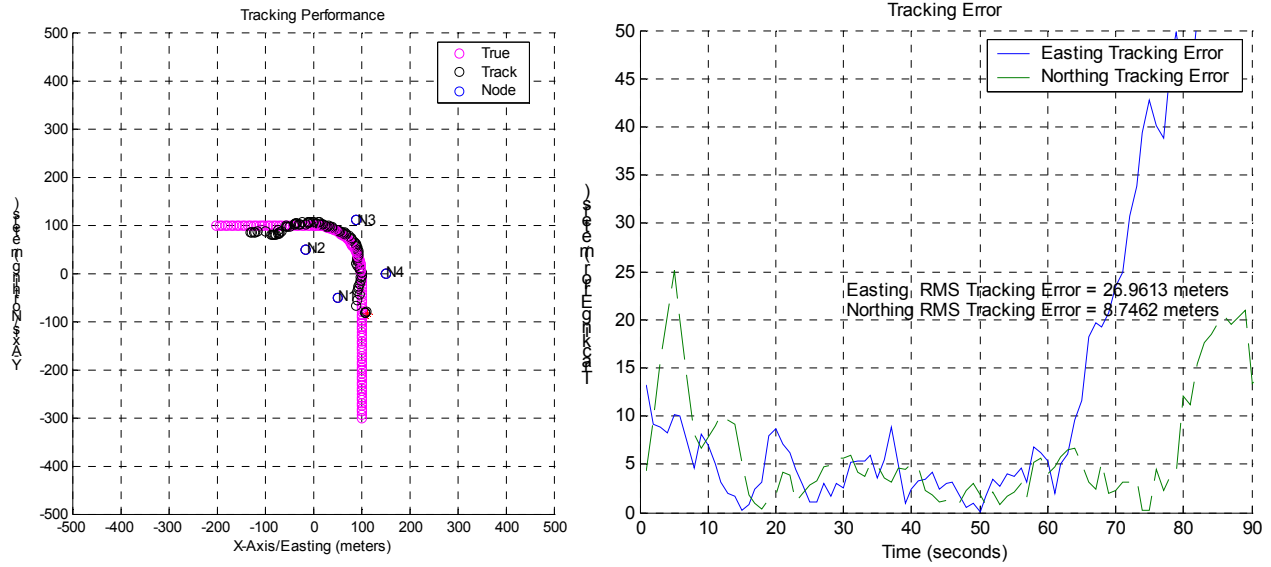Figure 6 Diamond Configuration Tracking Performance For Curved Track

Figure 7 Skewed-Diamond Configuration Tracking Performance For Curved Track

Table 2 Curved Track Monte Carlo Results

Node Configuration	X-Axis/Easting Error (m)			Y-Axis/Northing Error (m)			Spatial Coverage (m)		
	min	max	avg	min	max	avg	min	max	avg
Box	10.4	56.7	30.3	4.1	25.8	11.8	380	514	453
Diamond	17.3	45.1	34.3	5.2	27.3	12.9	337	508	435
Skewed Diamond	13.2	42.9	27.3	5.3	18.5	10.6	343	527	450

From the Monte Carlo results provided in Table 2, it was observed that the "skewed-diamond" nodal configuration appeared to provide the best combination of spatial coverage and rms tracking performance for the curved track-type.

"SENSOR-FIELD" TRADE STUDIES

For any given sensor field, a primary goal of a distributed sensor system is to maintain successful target track over a desired region within the sensor field. The sensor field utilized for this work is the Aberdeen test-track located at Spesutie Island. Consequently, the desired goal for this work is to determine the number and configuration of nodes necessary to maintain successful track on a vehicle traveling around the Aberdeen test-track. In order to achieve this, the results from the previous "track-type" trade studies established the following guidelines for node placement within the Aberdeen test-track sensor field:

1. Box nodal configurations were used for all straight sections of the test-track.
2. Skewed-diamond nodal configurations were used for all curved sections of the test-track.

In addition, instead of having a single leg of the test-track run through the center of the nodes (as was the case for the "track-type" trade studies), the "straight-track" nodes were slightly offset in the negative Easting direction in an attempt to maintain adequate sensor coverage for both legs of the test-track.

Figure 8 illustrates a sample of the tracking performance using the aforementioned nodal placement guidelines and 16 nodes[3]. Monte Carlo performance data is provide in Table 3. From Figure 8 and Table 3, it can be seen that very accurate tracking performance was achieved over the entire Aberdeen test-track.
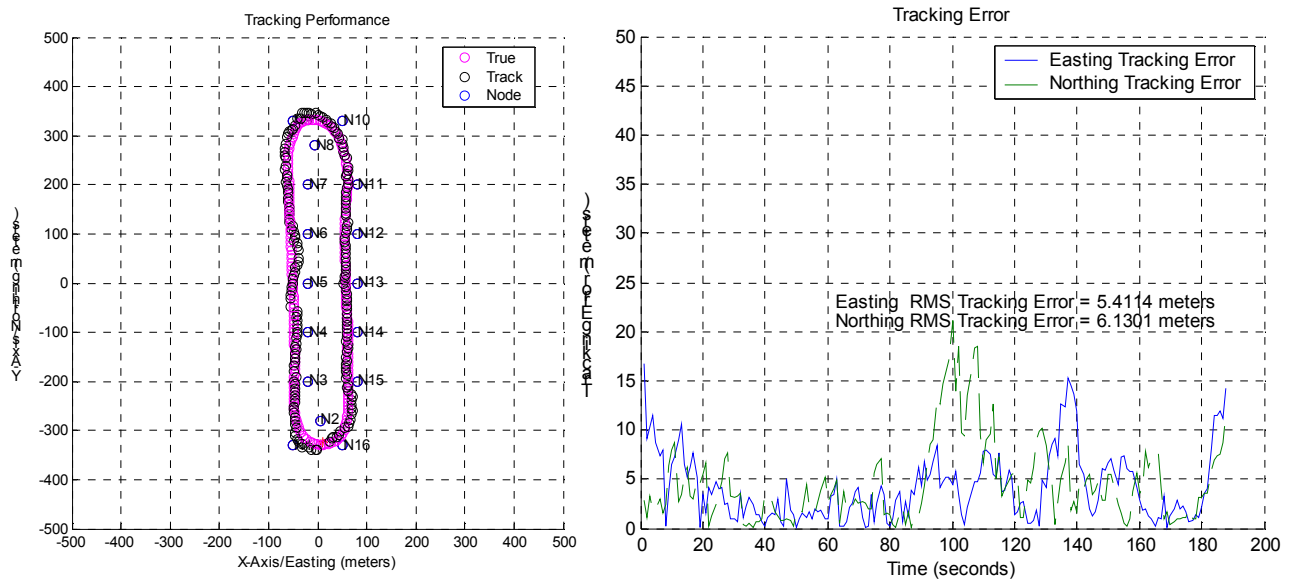

Figure 8 Aberdeen Tracking Performance Using 16 Nodes

Table 3 Aberdeen Monte Carlo Results (16 Nodes)

Node Configuration	X-Axis/Easting Error (m)			Y-Axis/Northing Error (m)			Spatial Coverage (m)		
	min	max	avg	min	max	avg	min	max	avg
16 Nodes	3.9	6.4	5.0	6.3	10.6	8.4	1300	1388	1359

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[3] Note that the Aberdeen truth data starts at "6:00" and travels counter-clockwise one rotation.

Next, it was desired to determine if comparable system performance could be obtained while using fewer nodes. To attempt this, the number of "straight-track" nodes was reduced from ten to two, and the "center node" for each curved section of the test-track was moved toward the center of the sensor field in order to assist tracking performance at the non-curved regions. Figure 9 illustrates a sample of the tracking performance using 8 nodes based upon the aforementioned guidelines. Monte Carlo performance data is provided in Table 4.
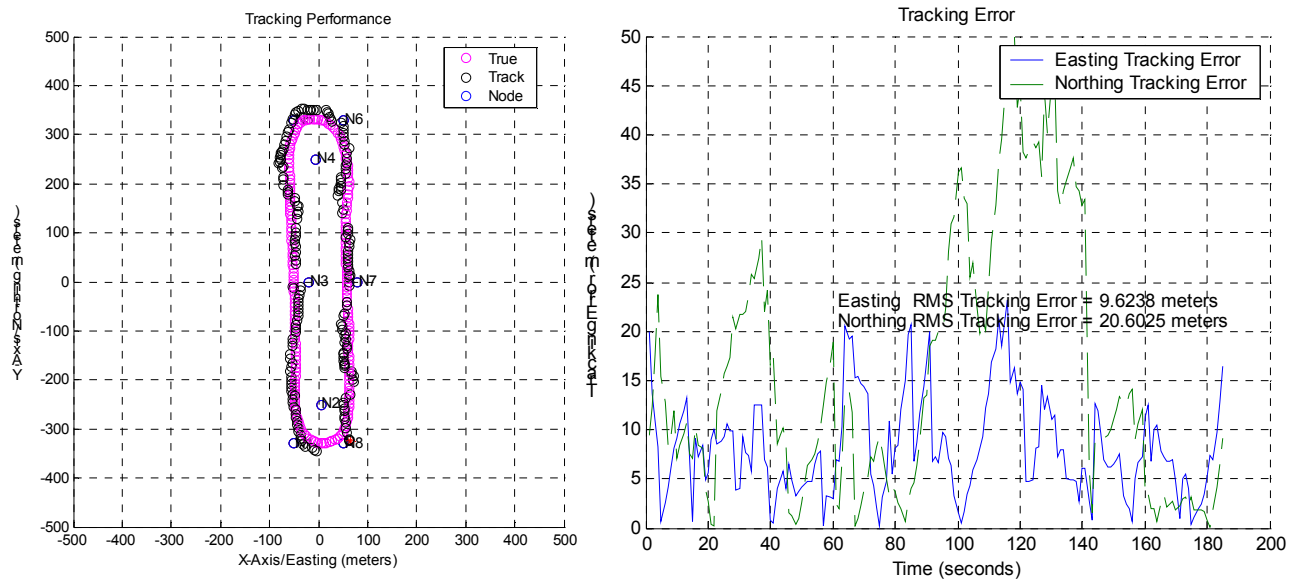

Figure 9 Aberdeen Tracking Performance Using 8 Nodes

Table 4 Aberdeen Monte Carlo Results
(8 Nodes)

Node Configuration	X-Axis/Easting Error (m)			Y-Axis/Northing Error (m)			Spatial Coverage (m)		
	min	max	Avg	min	max	avg	min	max	avg
8 Nodes	7.0	16.8	10.8	9.3	38.4	21.8	44	1381	713

From Figure 9, it can be seen that the tracking performance for the 8 node configuration degraded primarily at the curved regions of the test–track (most likely due to the relocation of the "center node") as well as at the straight regions of the test-track where the nodal spatial coverage was sparse. Consequently, in order to improve the system performance at these "trouble-spots", the following adjustments to the 8 node configuration were made:

1. Re-locate the "center nodes" for the curved regions of the test-track back to their original positions.
2. Add three more nodes for the straight regions of the test-track.

Figure 10 illustrates a sample of the system performance with the aforementioned nodal configuration adjustments implemented which results in a 11 node configuration. Monte Carlo performance is provided in Table 5.
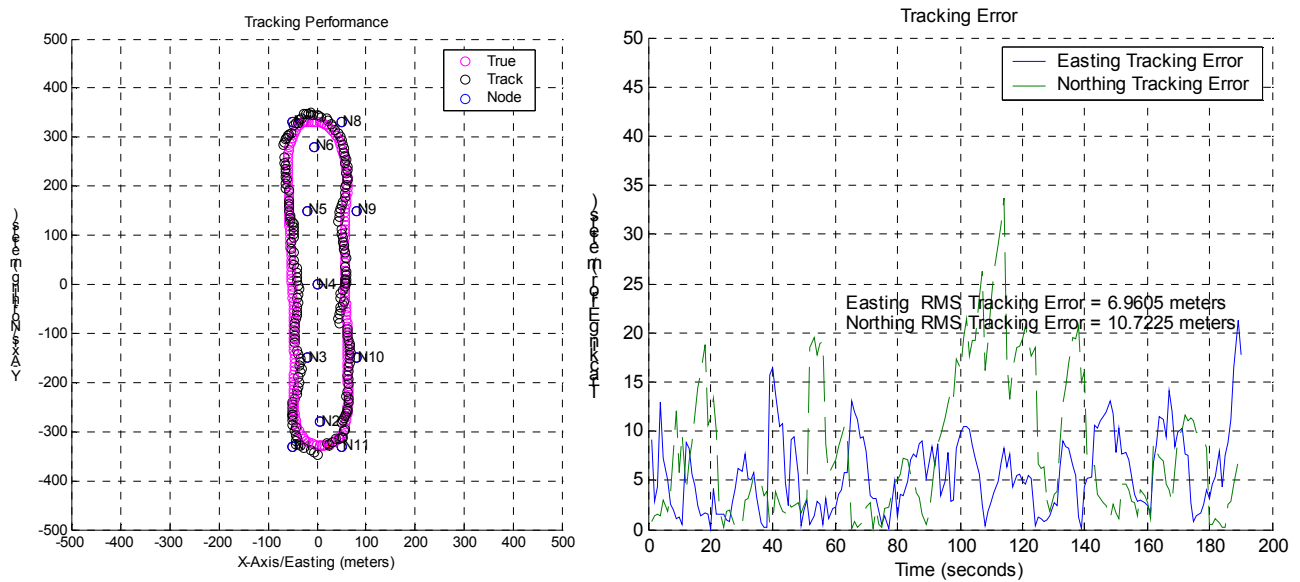

Figure 10 Aberdeen Tracking Performance Using 11 Nodes

Table 5 Aberdeen Monte Carlo Results
(11 Nodes)

Node Configuration	X-Axis/Easting Error (m)			Y-Axis/Northing Error (m)			Spatial Coverage (m)		
	min	max	Avg	min	max	avg	min	max	avg
11 Nodes	5.6	9.5	7.6	8.7	17.3	11.8	162	1388	1174

From Figure 10 and Table 5, it can be seen that the 11 node configuration significantly improved the overall tracking performance as compared to the 8 node configuration. In addition, it was also observed that the 11 node configuration approaches comparable tracking performance to that of the original 16 node configuration.

SUMMARY

A simulation tool has been developed for the purpose of performing trade studies between data fusion/tracking algorithms and sensor node configurations for distributed sensor system applications. The simulation tool allows the user to control the number and configuration of nodes within a given sensor field in order to analyze system performance as a function of sensor node placement. Simulation results indicate that the proper placement of sensor nodes within a given field is capable of providing significant improvements in system performance. It is anticipated that the simulation tool developed for this work will be used to assist in the sensor node placement for future field tests, exercises and operational scenarios.

REFERENCES

1. Blatt, S., Haney, P., "Resolution of Multiple Targets in a Dense Sensor Field," *Proceedings of the Fifth Annual Federated Laboratory Symposium on Advanced Sensors*, pp. 11-13, March 2001.